Collider - Accelerator Department / SNS Power Supply Systems
**BROOKHAVEN NATIONAL LABORATORY**
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# SPECIFICATION FOR A 100.625 MHZ RF POWER AMPLIFIER FOR THE EBIS PROGRAM

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## 1.0 Overview

The Electron-Beam Ion Source (EBIS) program, a new heavy-ion pre-injector for the Relativistic Heavy-Ion Collider (RHIC), comprising the high charge-state EBIS and a Radio Frequency Quadrupole (RFQ), has been proposed to replace the present Pre-injector.

The new pre-injector will be a reliable, low-maintenance Linear-Accelerator (Linac)-based facility. Linac-based pre-injectors are used in most accelerator and collider facilities, with the exception of RHIC. Two RF Power Amplifier systems are required, at 100.625 MHz, each producing 350 kW peak-power pulses of 1 millisecond duration, at a rate of 5 pulses/second, for the RFQ and the Linac (based on an Interdigital-H structure).

## 2.0 Scope

2.1 This specification, in conjunction with other documents, defines the performance, design requirements, configuration, construction, materials, quality assurance, inspection, testing, workmanship and packaging of the RF Power Amplifiers (RFPA). The RFPAs will be completely assembled units that will be installed and interfaced to remote control computers by BNL. They shall include all the hardware, both analog and digital (off/on, interlock, status) to enable this interface. These RFPAs shall be installed as part of a large accelerator system and must operate continuously for long periods of time in an unmanned area. The power supply must exhibit a high level of reliability and be thoroughly interlocked.

1.2 The seller shall furnish all equipment, materials, tools, facilities and labor to perform all the work necessary to design, manufacture and test the power supply per this specification. The seller shall also provide all labor and resources to produce detailed up-to-date documentation of the power supply as built. The RFPAs shall be designed to have an expected service life in excess of twenty years.

1.3 The design of the RFPAs must be conservative, using standard techniques and commercially available component parts that insure high reliability and minimum maintenance. Detailed parameters for these units are given in the Appendix 1, Specification Data Sheet. After award of contract, no deviation from this specification is permitted unless written approval is obtained from the BNL Division of Procurement & Property Management (PPM).

## 3.0 General Requirements

This section of the specification describes the performance and physical characteristics of the units required. Alternate products or schemes offered by the seller that may provide equal or better performance and reliability may be presented, but will be subject to approval by BNL.

### 3.1 Parts, Materials and Processes

3.1.1 Permanently installed hazardous or toxic materials shall not be used. Asbestos or asbestos-type insulation, insulating or dielectric fluids containing PCB's, etc., shall not be used. Where a choice of materials is available, e.g. cables, support hardware, etc., preference shall be given to material or equipment exhibiting a higher level of fire retardancy, low oxygen content, etc. With delivery, Seller shall provide to BNL any applicable Material Safety Data Sheets as required by the Occupational Safety and Health Act and applicable regulations including, without exception, as required under 29 CFR 1910.1200.

3.1.2 The specifications for the various portions of the work describe certain special materials, processes and products of manufacture, which are required. Should the seller propose to furnish other "equal" materials, processes, or products either in substitution for, or as an alternate to the specifications, such substitutions must be approved by BNL Procurement & Property Management division (PPM) in writing. Decision as to the equality of any materials, processes and products to those specified shall be final, but the approval of BNL shall not relieve the seller from their responsibility concerning such work or affect the guarantee covering all parts of the work.

3.1.3 The BNL Cognizant Engineer shall have final approval as to the determination of design parameters, operational margins, specification interpretation, control, protection and testing. Differences between the seller's proposal and the standards or Brookhaven's requirements shall be resolved by the Cognizant Engineer's determination. Sellers shall obtain written approval from BNL before proceeding with the final design and fabrication. No deviation from the specification will be allowed unless specifically authorized by BNL in writing.

3.1.4 The Seller will be held responsible for the design, construction and testing of the RFPAs. However, the Seller will not be held responsible for the installation or system testing at BNL.

3.2 Documentation

3.2.1 Paper Drawings - Upon delivery of the equipment, five (5) sets of final as built, signed prints shall be supplied by the Seller. These prints shall be made to the highest professional drafting standards. These prints shall include schematics of all circuits, and all assemblies, down to the card level. Each component shall be identified by its reference number, as well as its commercial part number. No markings shall be obliterated.

3.2.2 Electronic Drawings - All drawings supplied in paragraph 3.2.1 shall be supplied in electronic form. AutoCAD format is acceptable. Any other format must be approved by BNL.

3.2.3 Paper Manuals - Five (5) sets of bound design and operations manuals shall be shipped with the equipment. They shall include final parts lists, recommended spare parts lists, technical descriptions of theRFPA operation and maintenance recommendations, detailed circuit descriptions, description of critical adjustments and potentiometer settings, and data sheets on gauges, meters, fuses, semiconductors, relays, valves, and other pertinent components.

3.2.4 Electronic Manuals - The manuals supplied in paragraph 3.2.3 shall be supplied in electronic form. Microsoft Word for Windows format is acceptable. Any other format must be approved by BNL.

3.2.5 Software Documentation - If software is used to program any device, such as microcontrollers, programmable gate arrays, PLCs, or any other device, the source code for that software shall be delivered in paper and electronic forms.

3.2.6 Traveler - A traveler shall follow the power supply through production. This traveler shall contain critical settings for the power supply and shall serve as a history of its production. A copy of this traveler shall be supplied to Brookhaven. The traveler shall contain as a minimum, components selected at test, potentiometer settings, torque settings, test results, trip settings, etc.

3.3 Design Reviews

3.3.1 Prior to awarding a contract under this specification a pre-award meeting shall, at BNL's option, be held. At this meeting a preliminary review of the submitted design will be done, and the capability of the seller to comply with this contract in a timely manner will be evaluated.

3.3.2 The final design review (FDR) shall be held within eight (8) weeks after receipt of order and prior to the start of fabrication. Three (3) sets of all electrical schematic drawings, mechanical assembly drawings, a manufacturing schedule, a preliminary acceptance test procedure, and a complete parts list shall be submitted to

BNL at least two (2) weeks prior to the FDR date. Agreement shall be reached during the FDR not only on the drawings and material submitted, but also on the seller's manufacturing plan, preliminary test procedure and schedule. Components and materials used in the cooling system shall also be reviewed at this time. The results of the FDR shall be documented by the seller and submitted to BNL for approval. After written approval of the FDR by BNL the seller shall promptly begin assembly.

## 4.0 Electrical Requirements

Detailed parameters for this power supply are listed in Appendix 1, Specification Data Sheet attached as the last section of this specification. All power supplies must also meet the RF specifications, which are given here.

### 4.1 RF Requirements

4.1.1 Each RF Power Amplifier shall include, as a minimum, a Final Power Amplifier (FPA), an Intermediate Power Amplifier (IPA) and their associated RF circuits (cavities), and a solid-state Driver Amplifier (PDA), with all of the requisite power supplies (plate, screen, control grid, filament, etc.), energy-storage capacitor banks, high-speed (micro-second response time) protective devices (crowbar or solid-state opening switch), pulse modulators (if required), and all provisions for cooling each stage.

4.1.2 The FPA shall be designed in accordance with CPI's tech note (attached at the end of this document) describing how to estimate and extend the tube lifetime. Calculations of the tube performance must be included and the tube lifetime should be ***good*** to ***excellent***. After evaluating single tube FPA design, neither CPI 4CW150000 nor Thales TH535 will be able to provide 350 kW pulsed power output, while giving us good lifetime expectancy. Therefore, alternative tubes, or dual tube design with either push-pull or parallel configuration shall be implemented.

4.1.2 Low Level RF (LLRF) will control amplitude and phase. The PA has to have enough dynamic gain reserve to accommodate pulse flatness to 0.1%, and phase reproducibility to 0.1 degree.

### 4.2 RFI/EMI:

4.2.1 Maximum occupational exposures from the amplifier should not exceed:

**4.2.1.1 Electric Field Strength (E) = 61.4 V/m with an averaging time of 6 minutes.**

**4.2.1.2 Magnetic Field Strength (H) = 0.163 A/m with an averaging time of 6 minutes.**

4.2.2 The above threshold limit values (TLVs) represent near field measurements spatially averaged over the area equivalent to the vertical cross section of the human body. Measurements shall be made with appropriate instrumentation, which has been calibrated by a recognized authority.

4.2 Power Connections

4.3.1 Each phase of the AC input terminals shall be sized for at least 150% of rated current. The AC terminals shall be phased A-B-C, from left to right when facing the AC compartment door and shall be clearly labeled.

4.3.2 The location of AC input shall be specified in the Specification Data Sheets. Access doors shall be provided for AC input hookups and for servicing. The doors shall be electrically interlocked with micro switches and be capable of being mechanically locked with Kirk type locks.

4.3.3 The location of DC output bus compartment shall be specified in the Specification Data Sheets. This area shall be isolated from all other compartments. Access doors shall be capable of being mechanically locked with Kirk type locks and shall be electrically interlocked with micro switches.

4.5 Electrical Construction Methods

4.5.1 All transformers and reactors will be air cooled and designed with Class 220 °C insulation but shall only operate up to a Class 180 °C rating. Only copper conductors with no splices will be accepted for windings. Transformers should be braced for rectifier service and be able to handle the worst-case fault currents.

4.5.2 Any electrical cable and bus-work used shall be made of copper and of sufficient ratings and cross-section such that they shall not exhibit a temperature rise of greater than 30°C rise above ambient at maximum load.

4.5.3 All low level control wiring shall be type AWM appliance wire, 600 volt, 105 °C, stranded copper conductor or approved equal. All wires shall be labeled for circuit identification at all termination points. Proper insulators and supports shall be used.

4.5.4 All cable insulation used in this system shall be of a self extinguishing, low flame propagation, low smoke type and meet IEEE 383 vertical flame tests. The Seller shall include in their proposal a list of the insulating material that will be used.

4.6 Protection and Interlocks

4.6.1 The following devices or systems, shall be incorporated in the power supply and shall be used to interlock the power supply to internal and external control devices. All of the interlocks and controls of each power supply shall be connected to a computer controller. All faults should latch until reset and be annunciated on front panel. All control, interlock devices and circuits must meet the high potential tests of section 7.0.

4.6.2 Over temperature protection of rectifier cells will be required. The over temperature detection devices shall be thermostat type switches (or equal) with contacts that are electrically isolated from the heat-sink, and must be capable of meeting the high potential test in section 7.0. The thermostats shall be automatic reset type with normally closed contacts, they should be latched in the PLC. The trip point of the thermostat is to be set to protect the rectifier cells from exceeding the manufacturer's recommended maximum safe operating case temperature for the maximum junction temperature given in section 4.7.

4.6.3 Water flow switches shall be installed on the return leg of every parallel water path for loss of cooling water protection. A pressure differential switch shall be installed in each power supply to protect against loss of pressure. Shut-off valves shall be placed on every parallel water path to aid in back flushing the water paths. The water flow switches and the differential pressure switch shall be wired to the computer controller for interlock control and alarm indication.

4.6.4 The Seller shall provide AC line monitoring relays. This will include phase sequence, loss of phase, and under voltage. Statuses will be wired to the computer controller for interlock control and alarm indication.

4.6.5 Three phase AC over-current relays shall be provided by the Seller to sense AC over current in primary input of power supply. The seller supplied current transformers shall be mounted in the power supply enclosure near the seller supplied contactor. The over current devices shall provide interlock contacts **wired directly** in series with the master interlock relay contacts. The AC over current relays shall also provide status information to the computer controller for other interlock control and alarm indication.

4.6.6 The power supply shall have a DC over current sensing device that has an adjustable trip setting from 10 percent to 110 percent of rated DC output current. The over current device shall use an independent shunt or LEM for current sensing. The DC over current device shall be mounted in the control compartment of the power supply. The DC over current device shall be **wired directly** in series with the master interlock relay coil, so that an over current condition shall open the master interlock relay contacts. The DC over current device shall also provide status information to the computer controller for other interlock control and alarm indication.

4.6.7 Door interlock micro-switches shall be mounted on all hinged doors of the power supply that lead to high power AC and DC circuitry. The switches used shall be similar to the Micro-Switch type V-3. The door switches shall be wired directly in series with the master interlock relay contacts. The door interlock micro-switches shall provide status information to the computer controller.

4.6.8 A cubicle over temperature interlock shall be provided by the Seller. The device shall be adjustable, between 100 °F and 200 °F, and shall provide status for the computer controller.

4.6.9 Control circuits shall be designed in a fail-safe manner so that loss of power does not result in a hazardous operating condition. Protective interlock circuits and power supply controls shall be designed so that reactivation of the interlock circuit (i.e., completing the circuit) will not result in an automatic restoration of power to the equipment.

4.6.10 The Seller shall provide DC over-voltage protection and interlocking circuitry, which shall be capable of protecting the power supply from over-voltage conditions at the DC terminals. This protection shall be so designed that it can be activated by internal sensing within the power supply. The over-voltage protection equipment shall also provide a detection circuit that will be wired directly to the master interlock relay contacts. Status information shall also be provided to the computer controller.

4.6.11 Provisions shall be made for two external BNL interlocks. One interlock shall be for load fault and the other for system security. Interlocks shall be wired directly in series with the master interlock relay through an appropriate terminal board. Status of either of the remote interlocks shall be monitored by computer controller and annunciated.

4.6.12 The status of all interlocks shall be locally annunciated and shall be brought to the PLC input module . The following is a list of some of the status that shall be required in the base proposal. The exact number of status read-backs and alarms required to adequately protect the power supply cannot be finalized until the Sellers design is complete. This list will be finalized at the FDR.

- 4.6.12.1 Input AC line fault: Over-current, Over-voltage, phase loss, Phase Sequence
- 4.6.12.2 DC Output fault: Over-current, Over-voltage
- 4.6.12.3 Over temperatures
- 4.6.12.4 Water fault: flow, pressure
- 4.6.12.5 Blown fuses-indication and location
- 4.6.12.6 Door interlocks.
- 4.6.12.7 Two external (load and security) interlocks
- 4.6.12.8 RFPA states. OFF, Standby, ON.

## 4.7 Power Semiconductor Ratings

4.7.1 The peak inverse voltage (PIV) and peak forward voltage (PFV) rating of all power semiconductors shall be rated for three (3) times their peak circuit operating voltage or greater.

5.0 Control and Instrumentation Interface

The units shall be fully controllable using standard Allen-Bradley Programmable Logic Controller (PLC) equipment, with an optional remote control interface. A meter panel shall be equipped with analog panel meters to indicate all operating parameters. The operator console shall be equipped with a touch- screen monitor or a push-button panel, key switches and an emergency-off button.

5.1 Control States

**5.1.0 OFF command should be operational from Remote or Local control, independent of the position of Remote/Local switch. STBY push button should be operational to change the PS state from ON to STBY from Remote or Local control, independent of the position of Remote/Local switch.**

This section defines the controls states, and the transitions between states.

5.1.1 OFF - When AC power is applied to the power supply, it shall automatically go into this OFF state.

a) AC power is connected to the power supply.
b) The main contactor is open, preventing AC power from being applied to the power stages of the unit (rectifiers, SCRs, transformer inputs). No power is delivered to the load.
c) The fans are off.
d) Internal control power, sufficient for the unit to respond to other commands and indicate state is available.
e) The OFF indicator is illuminated, and the OFF state is indicated as a status readback to the PLC.

5.1.2 STANDBY

a) AC power is connected to the power supply.
b) The main contactor is open, preventing AC power from being applied to the power stages of the unit (rectifiers, SCRs, transformer inputs). No power is delivered to the load.
c) The fans are on.
d) Internal control power is applied to all circuit boards, including regulators and control circuitry.
e) The STANDBY indicator is illuminated, and the STANDBY state is indicated as a status readback to the PLC(is there a PLC?)
f) Issuing the STANDBY command shall simultaneously issue a rest command to all interlocks. If any interlocks have not cleared the power supply shall stay in STANDBY but with a fault indication. If the faults

have reset the power supply will be armed to move to the “ON” state.

### 5.1.3 ON

a) AC power is connected to the power supply.
b) The main contactor is closed, applying AC power to the power stages of the unit (rectifiers, SCRs, transformer inputs). The load is powered.
c) The fans are on.
d) Internal control power is applied to all circuit boards, including regulators and control circuitry.
e) ALL faults are cleared
e) The ON indicator is illuminated, and the ON state is indicated as a status readback to the PLC.

### 5.1.4 FAULT

a) AC power is connected to the power supply.
b) The main contactor is open, preventing AC power from being applied to the power stages of the unit (rectifiers, SCRs, transformer inputs). No power is delivered to the load.
c) The fans are on.
d) Internal control power is applied to all circuit boards, including regulators and control circuitry.
e) The STANDBY and FAULT indicators are illuminated, and the STANDBY state is indicated. The SUMMARY FAULT and individual faults are sent as status readbacks to the PLC.
f) Fault events are latched in this state.

### 5.1.5 State Transitions - State transitions shall be as shown in Figure 5-1.

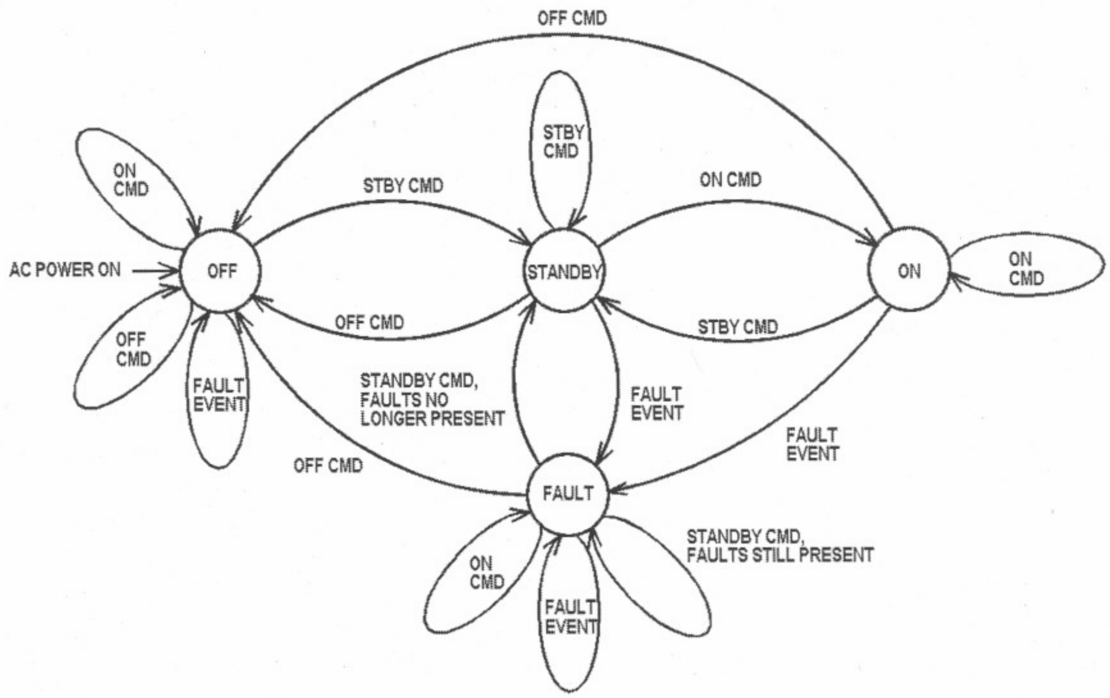


**Figure 5-1. State Transition**

5.2 Operating Modes

5.2.1 The power supply shall operate in either Local or Remote mode as controlled by a front panel switch. In Local the supply will be controlled from vendor supplied controls and reference. In Remote the power supply will be controlled via the relay interface:
OFF ----normally closed contact;
STBY—normally open contact, (momentary) ;
ON---- normally open contact, (momentary).
Remote mode status will be reported to the PLC as true.
Switching the power supply between local and remote states shall put the power supply in STANDBY.

5.3 Local Instrumentation

5.3.1 There shall be front panel metering as described below. All monitoring will be fully functional in both Local and Remote modes.

5.3.1.1 An AC voltage meter to monitor input voltage line to line. There shall be a selector switch to allow metering of all three phases. The seller shall supply the necessary potential transformers.

5.3.1.2 An AC ammeter to monitor input line current. There shall be a selector switch to allow metering of all three phases. The selector switch shall be a "make before break" type, so as not to open circuit the CTs. The seller shall supply the necessary current transformers.

5.3.1.3 A DC voltmeter operated from a buffered output of DC potential transformer (DCPT) connected across the power supply output terminals. The DCPT shall have an accuracy of +/- 1 %. The DCPT shall be similar to the Liaisons Electroniques Module LV series. An isolated and buffered output shall be provided for local voltage monitoring.

5.3.1.4 A DC ammeter that shall operate from a buffered output of the DC current transducer used for regulation. The output current measurement shall have a stability of five (5) times better then the value specified for output current.

5.3.2 There shall be front panel SMA connectors as monitors to represent forward and reverse power at each stage, as described below.

5.3.2.1 Final Stage - A buffered monitor of the peak power, with a scale factor of 10V = 500 kW, a bandwidth of 1KHz, an accuracy of 1%, and capacity to drive 10KΩ.

5.3.2.2 All Other Stages - A buffered monitor of the peak power, with a scale factor that will allow a full range of possible values and will be easy to interpret at a full scale output of 10V. The monitors will have bandwidths of 10KHz, and accuracies of 1%, and the capacity to drive 10KΩ.

5.3.3 There shall be front panel LED indicators as described below:

5.3.3.1 State indicators (in the stated colors): OFF (green), STANDBY (yellow), ON (red), and FAULT (white).

5.3.3.2 Fault indicators: Each fault will be indicated with a white LED.

5.3.3.3 Interlock indicators: Each interlock will be indicated with a white LED.

5.4 Local Controls

5.4.1 Active in Both Local and Remote Modes - These controls are operated locally, but are fully functional in both Local and Remote Modes.

5.4.1.1 CRASH - A momentary switch, with a large red button, that when pressed, puts the power supply in the off mode regardless of current state, local inputs, or remote inputs.

5.4.1.2 LOCAL/REMOTE - This is a toggle action switch selects either the Local or Remote modes. The state of this switch is unaffected by power removal and re-application. Operating this switch shall drop the power supply to standby

5.4.1.3 Limit Setpoints - These setpoints are to accessible from a front panel, but shall be recessed, and require a screwdriver to make adjustments.

5.4.1.4 Local OFF switch must work in both local and remote.

5.4.2 Active in Local Mode Only - These controls are operated locally, and are functional in Local Mode only.

5.4.2.1 Mode Switches - These three momentary pushbutton switches, labeled OFF, STANDBY/RESET, and ON, are used to control the state of the power supply locally, as described in the state diagram, Figure 5-1 and in section 5.1.0.

5.4.2.2 Local Reference - There will be two ways to provide a local reference, as selected by a front panel toggle switch. In one position, the reference is provided by a ten turn potentiometer. In the second position, it is provided by a signal applied to a front panel BNC. This front panel BNC will be terminated with 100KΩ such that if there is no input, the reference will be near zero.

This will act as the local current reference in the current mode, and the local voltage reference in the voltage mode. Performance of the power supply when using a local reference will be equal to that in the remote mode, in either position of the reference toggle switch.

5.5 Remote RFPA Interface

The RFPA will be remotely controlled via the Allan Bradley PLC. The Seller shall purchase and wire following Allen-Bradley PLC Flex I/O interface devices:

1. 1 each ASB adapter (#1794-ASB)
2. 2 each digital input modules (#1794-IB16);
3. 6 each wire base (#1794-TB2),
4. 1 each 8 channel relay module (#1794- OW8).

The PLC shall be mounted inside the low voltage compartment accessible during the operation.

5.5.1 RF Interface

5.5.1.1 RF Input - The RF input to the RFPA shall be by means of an SMA connector on a front panel. The impedance of this input shall be 50 Ohms.

5.5.1.2 RF Monitoring - Forward and reverse power shall be monitored at each power level. This shall include the input, the final output, and the output of each intermediate power amplifier.

5.5.2 Digital Interface

5.5.2.1 Digital Outputs - There are three digital outputs from the PLC to the power supply. They are designed to provide dry relay contacts from the 1794-OW8. ON and STBY are Normally Open (NO) contacts and the OFF is Normally Closed (NC).

5.5.2.2 Digital Inputs - There are sixteen digital inputs to the PLC 1794-IB16 from the power supply. They accept 24 volt level. All outputs are TRUE high.

5.5.2.2.1 Interlocks:

1. DC OL
2. AC OL
3. Input phase loss
4. Input phase sequence
5. VSWR at each stage (individually identified)
6. Over temperature
7. Water flow
8. Fuse
9. Door open
10. External load fault
11. external interlock
12. Ground fault

5.5.2.2.2 Statuses:

1. ON
2. OFF
3. STBY

5.6 External Interlocks

The function of the external interlocks is to shut down the power supply in response to external events that could cause overload conditions to the power supply or it's load

5.6.1 Terminal Block

5.6.1.1 Physical Characteristics - An eight position terminal block with screw terminals will be provided for interface with the external interlocks. The terminal block shall be able to accommodate wires in the range of AWG #22 to AWG #16.

5.6.1.2 Shipping / Testing Jumpers - The power supply will be shipped with all interlock connections shorted with a distinctly marked jumpers. These will be removed after installation.

5.6.2 Operational Details

5.6.2.1 Operation - The interlock inputs will be connected to a normally closed dry contact. When this contact opens, it will cause the RFPA to go into the FAULT mode as described in this RFPA specification.

5.6.2.2 Signal Levels - The contacts for these inputs are typically 1,000 feet away from the power supply. The voltage that appears on an open contact shall not be more than 30 Volts, but not less than 15 Volts. The current through a closed contact shall not be more than 100 mA, nor less than 10 mA.

## 6.0 Mechanical Considerations

6.1 Enclosure

6.1.1 The equipment shall be constructed in an all-metal cabinet which shall be in accordance with NEMA standards for Indoor Power Switch-gear as per publication SG5, latest edition.

6.1.2 The RFPA shall be partitioned into separate high current ac and dc compartments, as well as a separate low voltage or control compartment. The purpose of these compartments is to insure that electrically dangerous potentials are isolated, and through a Kirk type key coordinated locking arrangement, exposure to electrical hazards can be prevented.

6.1.3 The RFPA shall have a control compartment which shall be used to enclose all of the RFPA controls, over current devices, relays, protection, interlocks, system monitoring and status indications. This compartment shall be physically isolated from the high power compartments and shall be behind an unlocked door. The door shall not be interlocked. This compartment shall not contain any voltages greater than 125 volts AC rms or DC peak. Voltages greater than 50 volts AC rms or 50 volts DC peak shall be barriered.

6.1.4 Provisions shall be made for lifting the equipment so that the user can choose either overhead crane (e.g. lifting eyes) or fork lift (e.g. channels or I-beams). Such requirement will be finalized at the Design Review. The frame shall be made sufficiently rigid so that lifting and relocation shall not cause deformation or door misalignment.

6.1.5 The Seller shall provide an estimate of the RFPA size, weight, and a preliminary layout drawing in their proposal. The maximum dimensions of the units shall be within the values given in the Specification Data Sheets.

6.1.6 The finish of the cabinets shall consist of degreasing of the unit followed by a coat of rust-proofing paint and two coats of synthetic resin enamel, "Precaution Blue": Sherman-Williams - Grandville MI. - (616)-538-5505 Custom mix paint F73XXL6586-4331.

6.1.7 RFPA Nameplate - The vendor shall supply a stainless steel type "C" nameplate, mounted in plain sight, giving all standard information, including the following:

Manufacturer's name and address.
Manufacturer's part number.
BNL’s part number.

Manufacturer's Type and Serial Number.
Complete Input Ratings.
Complete Output Ratings.
Cooling Requirements.
Gross Weight of the Unit.
Date of Manufacture.
Specification Number.

6.2 Mechanical Construction Methods

6.2.1 All conductive bus work will be made of copper only. All bolted bus bar, fuse, and rectifier joints shall use Belleville washers, flat steel washers, lock nuts and a joint compound approved by Brookhaven. All bolts, washers and nuts shall be stainless steel. All copper bus bar connections shall be silver plated at all joints.

6.2.2 All bolts in blind locations shall have captive hardware.

6.2.3 All air filters shall be mounted on the outside of the unit and be of a size and type acceptable to BNL.

6.2.4 The noise level three feet away from the power supply from all sources within the cubicle including cooling fans, shall be less than 70 dB when the unit is on and operating.

6.2.5 The accessories, materials and supplies used in the RFPA design shall be of the highest quality or specification grade wherever possible. The Seller shall list in their proposal the manufacturer of fuses, relays, receptacles, terminal strips, wire, hardware, etc. Auxiliary relays shall be enclosed in dust proof cases and mounted in the power supply control compartment. Gold plated pins should be used in all IC sockets and critical connectors.

6.3 Cooling

All individual cooling system loops shall be connected in parallel and monitored separately. Each amplifier cabinet shall be equipped with a safety system, which guarantees the protection of all personnel. All doors providing access to hazardous voltages shall be locked with keys and equipped with automatic door interlock switches that are hard-wired to primary-power interrupting devices. All signals for equipment protection (cooling-water flow, temperatures, high reflected power and power supply overload conditions ) shall be directly tied to the amplifier control system.

## 7.0 Testing

7.1 General Testing Requirements

7.1.1 The RFPA shall be fully tested at the Seller's plant to insure complete compliance with this specification. All facilities, including the test load, shall be provided by the Seller at their plant for a full load test of the power supply. Three (3) weeks before these tests, the Seller shall provide the final test procedure to BNL for approval. Included in this procedure shall be test data sheets and interlock check out lists. Final tests at the Sellers plant shall be witnessed by Brookhaven prior to shipment. BNL shall conduct final acceptance tests of all units at Brookhaven

7.1.2 The BNL Cognizant Engineer and /or their representative shall have access to the Seller's facility during fabrication and testing. The Seller shall provide the facilities and instrumentation at their plant to perform all necessary tests to ensure compliance with all parts of the specification. The Seller shall provide ten (10) working days notice in advance of the test date so that BNL can make the necessary travel arrangements.

7.1.3 The testing shall include but not be limited to the specific tests outlined below. The Seller shall supply a detailed preliminary test procedure for individual components, sub-assemblies, and the completed power supply to BNL, for approval at the final design review.

7.1.4 All of the tests outlined in section 7.2 and 7.3, with the exception of section 7.2.2 High Potential Testing, are to be performed using Local controls and observing the statuses of the LED display on the Flex I/O.

7.2 Acceptance Testing

Each RFPA will undergo the testing described in this section.

7.2.1 Cooling Water Tests

7.2.1.1 Hydrostatic Pressure - The power supply shall be filled with water and pressurized to 250 psig. The power supply shall be isolated from the pressure source for a period of one hour and any pressure changes shall be recorded on the test data sheet at intervals of 15 minutes. Recorded data shall include water pressure to the nearest 0.5 psig and water temperature to the nearest 1°C. The power supply shall show no evidence of leakage or internal pressure change other than that resulting from any changes in water temperature.

7.2.1.2 Water Flow - The water flow in each parallel path and the total flow of water at a known differential pressure shall be measured. The temperature differential of the water paths shall also be recorded.

7.2.2 High Potential Testing

These tests are to be conducted for a minimum of one (1) minute at 60 Hz between the designated points and the power supply ground or frame. Actual leakage currents are to be monitored and recorded. Expected leakage current values shall be calculated and presented to BNL at time of design review.

7.2.2.1 All control circuits shall pass a hi-pot test to frame (ground) of 600V ac rms. The control circuits shall be connected to ground during high potential testing of the power circuitry.

7.2.2.2 AC terminals - 2500 V, rms.

7.2.3 Controls and Interlocks

7.2.3.1 Controls - The controls, OFF, Standby/Reset, and ON shall be tested in both the local and remote modes. Agreement with the state diagram shall be demonstrated.

7.2.3.2 Interlocks - All interlock protection and status indication circuits of the full system shall be checked for proper operation. Actual fault conditions shall be induced where possible and control and annunciation shall be checked up to the computer interface.

7.2.4 Electrical Performance

7.2.4.1 ON, OFF, and Emergency OFF switching transients across the output of the high power semiconductor components shall be measured and recorded.

7.2.4.2 The RFPA output ripple, as well as the line regulation, shall be checked at 50% and 100% of the output rated load current.

7.2.4.3 Other performance tests required:

a) Output power at low line
b) Noise measurement.
c) VSWR at each stage

7.2.5 Heat Run - A Heat run, as well as other performance tests shall be conducted on the completed assembled RFPA.

7.2.5.1 Preparation - The Seller shall install thermocouples on the power semiconductors, transformers, chokes, inlet water, outlet water, inlet air, and outlet air. The thermocouple location on individual components shall be placed on the "hot spot" for that component.

7.2.5.2 Ambient Resistance Measurements - The ambient resistance of the main transformers and chokes shall be measured. This data is required to calculate average temperatures.

7.2.5.3 Taking Data - The supply shall be operated continuously at full output power, for a period of 24 hours. Short periods of downtime to make measurements or adjustments will be accepted but the total of all such downtime shall not exceed one (1) hour.

## 8.0 Acceptance

For purpose of warranty under an order for these RFPAs, final inspection (acceptance) is defined as the successful completion of acceptance tests at BNL to substantiate the compliance of the RFPA with this specification. Final acceptance shall be completed within one (1) month after receipt of the units at BNL. The Seller will be notified of the test dates and may have a representative present to witness the tests. The Seller shall be held responsible for the contracted performance of the equipment produced and delivered to BNL.

Final Acceptance testing at BNL shall include any or all of the tests specified in section 7 of this specification, or any other standard tests deemed necessary by the BNL cognizant engineer to confirm conformance to the specification.

## 9.0 Quality Assurance and the Responsibility of the Seller

9.1 The Seller shall furnish a manufacturing plan and acceptance test procedures for approval by Brookhaven. Approval by Brookhaven shall not release the Seller from their responsibility for conceptual design, manufacturing, or any other mistakes committed in the fabrication of the power supply.

9.2 All purchased articles from subcontractors included in this power supply shall be clearly identified to indicate conformance to Seller's receiving inspection.

9.3 All elements of this equipment shall be covered by a guarantee against material and manufacturing faults. The Seller shall specify in detail the guarantee period and its provisions in their proposal. The guarantee period shall be for a period of at least two (2) calendar years from the final acceptance test date.

9.4 These quality assurance requirements are in addition to the following quality assurance requirements which will be found in Brookhaven document BNL-QA-101, attached to the purchase order. The following sections apply: 1, 2, 3, 3.1.2, 4.1,4.2 4.3, 4.4, 4.4.2, 4.4.3, 4.5 (except 10 days), 4.6 (except 3 weeks), 4.10, 4.10.1, 4.10.2, 4.10.3, 4.13, 4.16, 4.19, 4.21, 4.26, 4.34.

9.5 Traveler sheets shall follow each piece of equipment through production. These sheets shall document critical processes and settings for each article and shall serve as a history of its production as per section 3.2.6. Copies of these travelers shall be supplied to Brookhaven.

9.6 Copies of the test data sheets shall include lists of the instruments used to perform the tests, and the calibration due date of each instrument. Only calibrated test equipment shall be used.

9.7 The Seller shall establish those controls and processes necessary to ensure uniformity of all deliverable articles. All controls, inspections, tests and quality provisions established during development and pre-production tests shall be indicated on the applicable drawing and shall be performed on each deliverable article.

## 10.0 Preparation for Delivery

All units and parts of this equipment shall be properly packaged and delivered in undamaged condition to BNL. All water circuits shall be blown free of any water prior to packaging to prevent damage during shipping or storage under freezing conditions. The seller shall ship all RFPAs via air ride trucks.

## 11.0 Model Specific Requirements

Model specific requirements are included as attachments. There are two parts: a Specification Data Sheet and a Seller Data Sheet. The Seller Data Sheet must accompany any quote or proposal.

## Attachment A1 -Specification Data Sheet

| | |
|---|---|
| **Operating Frequency** | **100.625 MHz** |
| **Instantaneous Bandwidth** | **+/- 1 MHz** |
| **System Characteristic Impedance** | **50 Ohms** |
| **Peak Pulse RF Output Power (1 dB compression point)** | **350 kW** |
| **Average RF Output Power** | **1.75 kW** |
| **Pulse Duration** | **1.0 ms** |
| **Pulse Repetition Frequency** | **5 PPS** |
| **RF Pulse Rise and Fall Time into Resistive Load** | **10 μs max.** |
| **Peak RF Input Power** | **30 dBm, max.** |
| **Gain** | **60 dB** |
| **Non- harmonic Spurious Output (Power Supply Ripple Modulation, etc.)** | **Less than -70 dBc** |
| **Harmonic Power into Resistive Load** | **Less than -20 dBc** |
| **Intra-pulse Amplitude Modulation, (1 millisecond flat-top RF pulse)** | **0.1%, max closed loop; 1% open loop** |
| **Amplitude Jitter, one second period** | **0.1%, max closed loop; 1% open loop** |
| **Amplitude Drift, 1 hour period, for 99% of pulses** | **0.1%, max closed loop; 1% open loop** |
| **Amplitude Variation with Inlet Cooling Water temperature** | **0.02% / degree C, max** |
| **Intra-pulse Phase Modulation, (1 millisecond flat-top RF pulse)** | **0.1 degree max closed loop** |
| **Phase Jitter, one second period** | **0.1 degree max closed loop** |
| **Phase Drift, one hour period for 99% of pulses** | **0.1 degree max closed loop** |
| **Phase Variation with Inlet Water Temp.** | **0.5 degree/degree C, max open loop; 0.1 degree total closed loop** |
| **Output of the amplifier** | **3 & 1/8" EIA standard.** |

## Attachment A2 - Seller Data Sheet

**1. Power Supply Documentation**

a. Preliminary drawings ..........................................................................................

b. Block diagram ............................................................... (√) ________________

c. Preliminary production schedule ............................................ (√) ________________

**2. Tube Calculations**

a. Attach load line and tube calculations .................................... (√) ________________

**3. Estimated Reliability**

a. MTBF, hours..............................................................._________________________

**4. Total weight of the RFPA**......................................................_________________________

**5. Dimensions (H x W x L)** ........................................................_________________________

**6. Estimated heat rejected**

a. Air ...........................................................................................________________________

b. Water........................................................................................________________________

**7. Water Requirements**

a. Water flow (gpm)........................................................._________________________

b. Quality of water .........................................................._________________________

c. Conductivity of water ..................................................._________________________

d. Metals exposed to water .............................................._________________________

f Pressure Drop for required water Flow

**8. Exceptions to the Specification:**

# EXTENDING TRANSMITTER TUBE LIFE

*A carefully followed program of filament voltage management can substantially increase the life expectancy of transmitter power grid tubes. With today's rising operating costs, such a program makes good financial sense.*

One way to offset higher transmitter operating costs is to prolong tube life. For years station engineers have used various tricks to get longer operating life, with greater and lesser degrees of success. Success can be maximized, however, by understanding the various factors that affect tube life and then implementing a program of filament voltage management.

A few important factors that can aid in obtaining maximum tube life for your transmitter.

- Don't exceed the manufacturer's data sheet maximum ratings. Data sheets are available upon request from Eimac.
- Consult with Eimac's Application Engineering Department to assist in evaluating tube performance for a given application.
- Allow some headroom for the final power output tube so that the transmitter is capable of delivering power in excess of the desired operating level, without exceeding rated nominal filament voltage.

Figure 1 can be used as a basic guide to determine if a given transmitter and tube combination has a good probability of giving extended life service. Extended life service is defined as useful operating life beyond that normally achieved by operating at rated nominal filament voltage. The amperes/watt ratio is obtained by dividing average anode current by the product of filament voltage and filament current. If the amperes/watt ratio falls in the "good" to "excellent" range, excess emission is sufficient to permit filament voltage derating. At a lower filament voltage, the filament temperature is lowered, thus extending life. A typical FM transmitter on the market today may have an amperes/watt filament ratio of 0.002 to 0.003. This equipment would be considered an excellent choice to achieve extended tube life. On the other hand, if the amperes/watt ratio falls in the "poor" range, it is unlikely that filament derating is possible due to limited emission. Note that this guideline should be used for thoriated tungsten emitters only and **does not apply to oxide cathode-type tubes.**

### Instrumentation

*Are all tube elements metered in the transmitter?* Elements should be metered for both voltage and current, and meters should be red-lined to define operation within safe limits. Modern transmitters may incorporate a microprocessor-controlled circuit to monitor all pertinent parameters.

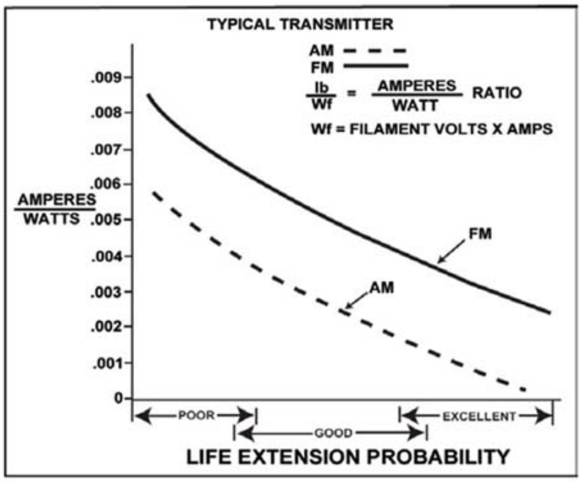


Figure 1. The probability of extended life service can be determined from this graph. Divide the average anode current in amperes by the product of filament voltage and current. The resulting amperes/watt ratio is projected horizontally to the appropriate curve. The vertical projection to the X-axis indicates the life extension probability.

In addition, the following controls are necessary if effective filament voltage management is to be undertaken:

- Power output metering for an FM transmitter or a distortion level meter for AM equipment
- *Accurate* filament voltage metering (an iron-vane instrument is preferred over the more common average responding RMS calibrated type
- The filament voltage measurement must be made at the tube socket terminals and filament voltage control should be capable of being adjusted in 0.1 V increments.
- A filament current meter – desirable but optional.

A means must be provided to hold filament voltage constant. If the filament voltage is permitted to vary in accordance with primary line voltage fluctuations, the effect on tube life can be devastating. One acceptable solution is to use a ferroresonant transformer or a line voltage regulator. These accessories are offered by some transmitter manufacturers as an option and should be seriously considered if a tube life extension program is planned.

## Transmitter Housekeeping

Once the transmitter has been placed in operation, tube life is in the hands of the chief engineer. The first action to prolong tube life falls into the category of routine maintenance. Most transmitter manufacturers have a routine maintenance schedule established in the equipment manual. This procedure must be followed carefully if operating costs are to be held to a minimum. During routine maintenance it is very important to watch for tube and/or socket discoloration, either of which can indicate overheating.

Look for discoloration around the top of the cooler near the anode core and at the bottom of the tube stem where the filament contacts are made. Review Figures 2, 3, 4 and 6 for examples of a tubes operating with inadequate cooling. It is possible for discoloration to appear in the areas mentioned if the transmitter has to operate in a dirty environment. If this is the case, the tube should be removed and cleaned with a mild detergent. After cleaning, the tube should be rinsed thoroughly to remove any detergent residue and blown dry with compressed air. If the discoloration remains, this is an indication that the tube has operated at too high a temperature. Check inlet and outlet air ducting and filters for possible air restriction. It may also be necessary to verify that the air blower is large enough to do the job and that it is operating at rated capacity.

With the tube removed, the socket should be blown or wiped clean and carefully inspected. Any discoloration in the socket finger stock caused by overheating could contribute to early tube failure. Finger stock that loses its temper through prolonged high temperature operation will no longer make adequate contact with the tube elements (Figure 7). A well-maintained socket will score the tube contacts when the tube is inserted. If all fingers are not making contact, more current flows through fewer contacting fingers, causing additional overheating and possible burn-through of contact rings.

## Filament Voltage Management

The useful operating life of a thoriated tungsten emitter can vary widely with filament voltage. Figure 8 describes the relative life expectancy with various filament voltage levels. Obviously, a well-managed filament voltage program will result in longer life expectancy. Improper management, on the other hand, can be very costly.

For a better understanding of this sensitive aging mechanism, the filament itself must be understood. Most filaments in high-power, gridded tubes are a mixture of tungsten and thoria with a chemical composition of $W + THO_2$. Filaments made of this wire are not suitable electron emitters for extended life applications until they are processed. Once the filament is formed into the desired shape and mounted, it is heated to approximately 2100°C in the presence of a hydrocarbon. The resulting thermochemical reaction forms di-tungsten carbide on

Figure 2 Improper cooling means short life. Discoloration of metal around the anode fins (left) indicates poor cooling or improper operation of the tube. A properly cooled and operated tube (right) shows no discoloration after many hours of use. Note: these pictured anodes were part of a collection being prepared for remanufacture.

Figure 3 Example of a severely overheated tube. The cooling fins are discolored and badly distorted. This type of overheating will cause premature tube failure.

Figure 4 Tube with evidence of overheating. Note the severe discoloration in the tube stem. This tube will have a very short lifetime.

Figure 5 This tube shows evidence of being well mounted in a socket for at least a year (note the marks on the contact ring from the finger stock). However, there is no discoloration of the stem and the anode fins have very little discoloration. This tube will last for a good period of time because it is being run under favorable conditions.

Figure 6 This tube appears to have been in a socket for only a short time, but already has evidence of overheating. Note the discolored stem and anode fins. This tube will have a short lifetime.

Figure 7 Bent and broken finger stock. Finger stock may become damaged due to effects of overheating or mishandling. Any broken finger stock must be repaired or replaced immediately to ensure long tube life.

the filament's surface. Life is proportional to the degree of carburization from this process. If the filament is overcarburized, however, it will be brittle and easily broken during handling and transporting. Therefore, only approximately 25% of the cross-sectional area of the wire is converted to di-tungsten carbide. Di-tungsten carbide has a higher resistance than tungsten; thus, the reaction can be carefully monitored by observing the reduction in filament current as the carburizing process proceeds.

As the tube is used, the filament slowly decarburizes. At some point in the filament's life, all of the di-tungsten carbide layer is depleted and the reduction of thoria to free thorium stops. The filament is now decarburized and can no longer be an effective electron emitter.

The key to extending the life of a thoriated tungsten filament emitter is to control operating temperature, which reduces the decarburization rate of the filament. Emitter temperature is a function of the total RMS power applied to the filament. Thus, filament voltage control is temperature control, because temperature varies directly with voltage. As the emitter temperature rises, the de-carburizing process is accelerated and tube life is shortened. Figure 8 shows that useful tube life can vary significantly with only a 5% change in filament voltage. NOTE: *If the filament voltage cannot be regulated to within ± 3%, the filament should always be operated at the rated nominal voltage specified on the data sheet.*

It should be noted that there is a danger to operating the emitter too much on the "cold" temperature side. It may become "poisoned." A cold filament acts as a getter; that is, it attracts contaminants. When a contaminant becomes attached to the surface of the emitter, the affected area of the emitter is rendered inactive, causing loss of emission. Should this happen, recovery is possible by operating the filament at full voltage for a period of time. Closely monitored operation of the filament at slightly below the rated nominal voltage, however, can extend tube life, if done properly.

Note that these filament management techniques should not be applied to oxide cathode tubes, such as the 3CX1500A7/8877. Running oxide cathodes too cold will result in internal arcs; and once that happens, an oxide cathode tube is not recoverable.

Of equally great importance to long tube life is the temperature of the other tube elements and of the ceramic-to-metal seals. Element temperatures can be held within proper limits by observing the maximum dissipation ratings listed in the tube's data sheet. Tube seal temperatures should be limited to 200°C at the lower anode seal under worst-case operating conditions. As tube element temperatures rise beyond 200°C, the release of contaminants locked in the materials used in manufacturing increase rapidly. These contaminants cause rapid depletion of the di-tungsten carbide layer of the filament.

When a new power tube is first installed in a transmitter, it **must** be operated at rated nominal filament voltage for the first 200 hours. This procedure is very important for two reasons. First, operation at normal temperature allows the getter (a device that chemically binds tube contaminates) to be more effective during the early period of a tube's life, when contaminants are more prevalent. This break-in period conditions the tube for future operation at lower filament voltages. Secondly, during the first 200 hours of operation, filament emission increases. It is necessary for the life extension program to start at the peak emission point.

A chart recorder or other device should be used to monitor variations in primary line voltage for several days of transmitter operation. The history of line voltage variations during on-air time must be reviewed prior to derating filament voltage. Plan to establish the derated voltage during the time period of historically **low** line voltage, as this is the worst-case condition. If line variation is greater than ± 3%, filament voltage must be regulated.

Record output power (FM) or distortion level (AM) with the tube operating at rated nominal filament voltage. Next, reduce the filament voltage in increments of 0.1V and record power or distortion levels at each increment. Allow one minute between each increment for the filament emission to stabilize.

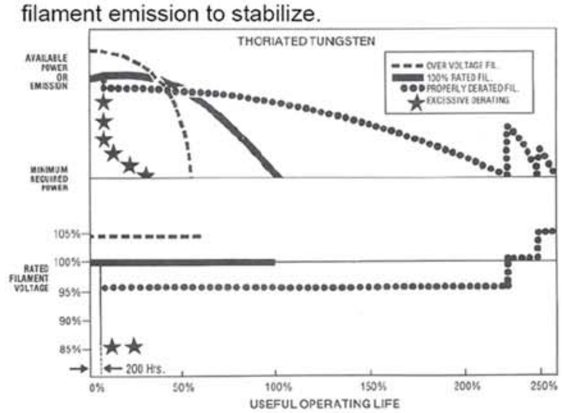


Figure 8 Filament voltage management allows extended tube life when accompanied by a continuing housekeeping program. When filament voltage is too high (dashes), power tube looses emission rapidly and normal operating life is not achieved. When filament is operated at rated voltage (solid curve, normal tube life is achieved in a majority of cases. With a filament voltage management program (bullets), extended tube life may be achieved. When the minimum required output power level is finally reached (right-hand portion of curve), the filament voltage may be raised to rated value, or above, to achieve additional useful operating life. If the filament is run "cool" (stars), extremely short life will result. Note that the filament voltage management program does not take effect until about 200 hours of operating time have passed.

When a noticeable change occurs in the output power or if the distortion level changes, the derating procedure must stop. Obviously, operation at and beyond this point is unwise since there is no margin allowed for a drop in line voltage. The voltage should be raised 0.2V above the critical voltage at which changes are observed to occur. Finally, recheck power output or distortion to see if they are acceptable at the chosen filament voltage level. Recheck again after 24 hours to determine if emission is stable and that the desired performance is maintained. If performance is not repeatable, the derating procedure must be repeated.

### Continuing the Program

The filament voltage should be held at the properly derated level as long as minimum power or maximum distortion requirements are met. Filament voltage can be raised to reestablish minimum requirements as necessary. This procedure will yield results similar to those shown in the illustration (Figure 8), to achieve as much as 10% to 15% additional life extension. When it becomes necessary to start increasing the filament voltage in order to maintain the same power output, it is time to order a new tube. Filament voltage can be increased as long as the increase results in maintaining minimum level requirements.

However, when a voltage increase fails to result in meeting output level requirements, filament emission must be considered inadequate and the tube should be replaced. Don't discard it or sell it for scrap! Put it on the shelf and save it. It will serve as a good emergency spare and may come in handy some day. Also, in AM transmitters, a low-emission RF amplifier tube can be shifted to modulator use where the peak filament emission requirement is not as severe.

Start planning for longer tube life now! Review the following steps you can take:

- Investigate the manufacturer's ratings on the power tubes in your present equipment, or the transmitter you plan to buy.
- Check that your transmitter has sufficient headroom. Is there a margin of safety in tube operation?
- Look for important instrumentation in the next transmitter you buy. Are all tube elements monitored for voltage and current in the transmitter?
- Whether your transmitter is new or old, start a filament life extension program.

Remember that each time you replace a power tube, the recommended derating procedure must be rerun. Voltage levels required with one tube do not apply to a replacement tube.